Measurement of the polarization amplitudes in $B_d \rightarrow J/\Psi K^*$ with LHCb

Christian Linn
Physikalisches Institut, Universität Heidelberg

Overview

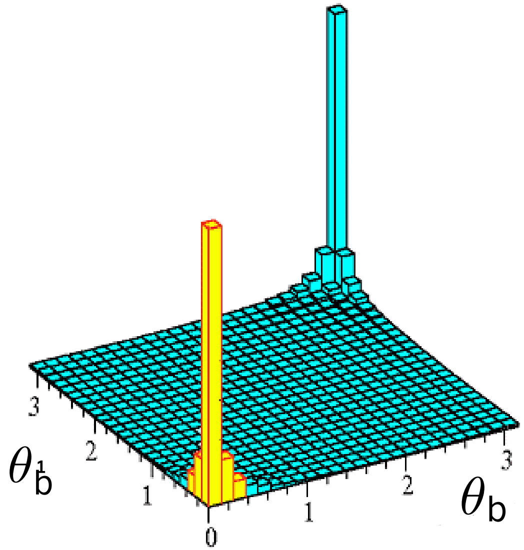
- The LHCb detector
- B – mixing
- Measuring CP violation in $B_s \rightarrow J/\Psi\ \Phi$
- The reference channel $B_d \rightarrow J/\Psi\ K^*$
- Systematic studies on detector acceptances
- Sensitivity for polarisation amplitudes
- Outlook

The LHCb detector

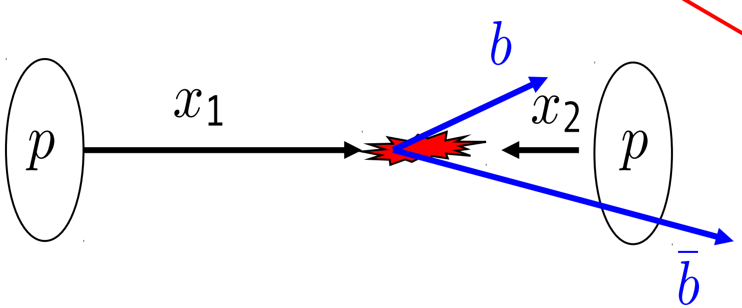
$5 \cdot 10^{11}$ B mesons per nominal year (= 2fb $^{-1}$)

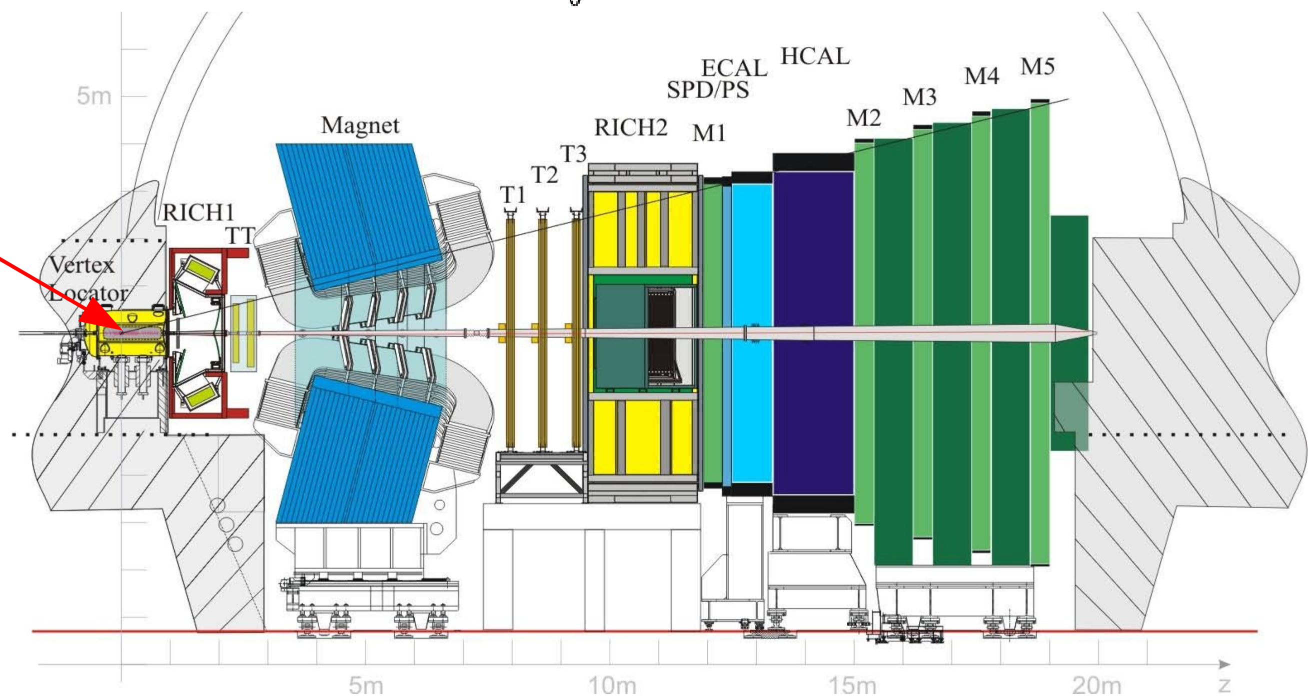
production mainly in forward direction

→ LHCb as single arm forward spectrometer



collision point



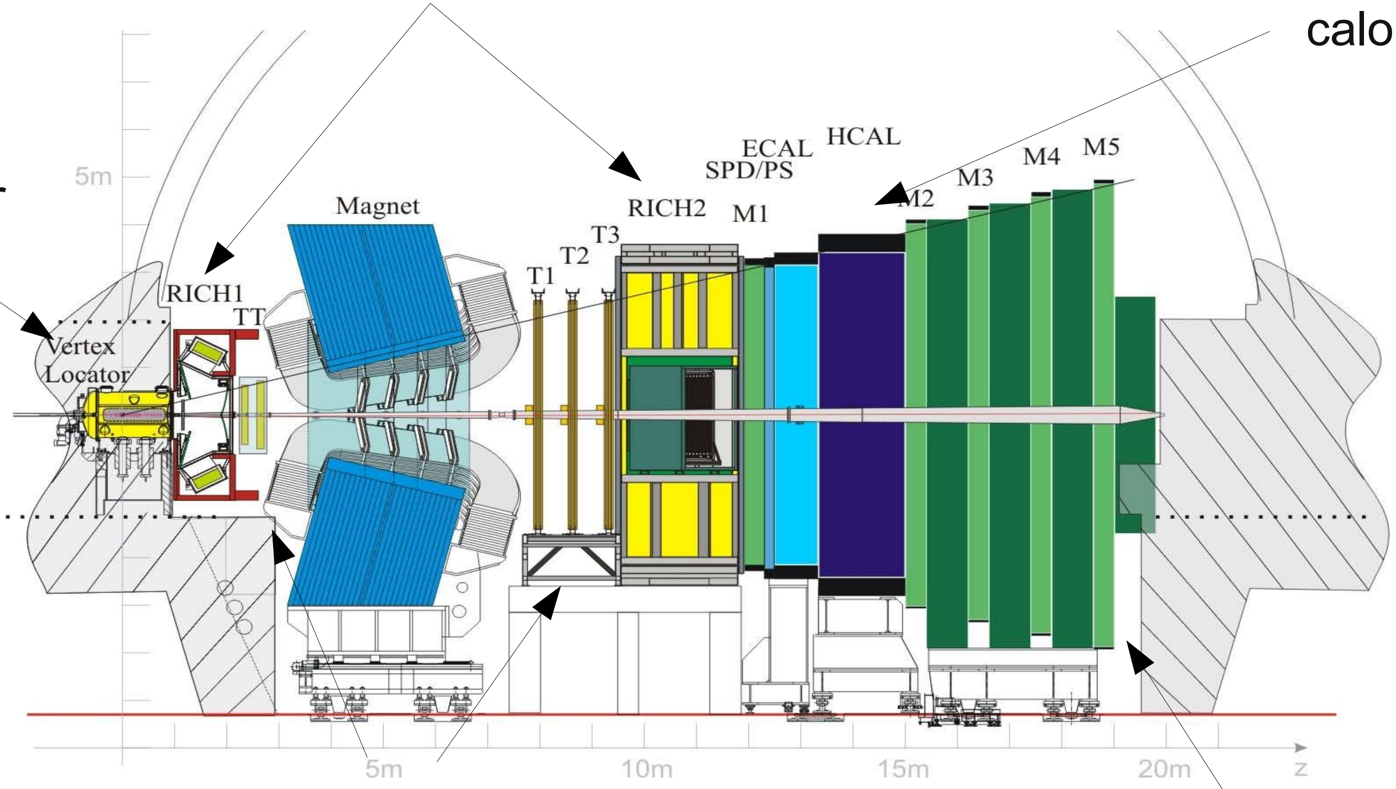


The LHCb detector

RICH detectors
(2 cherenkov detectors for particle identification)
momentum range 1 – 100 GeV

calorimeters

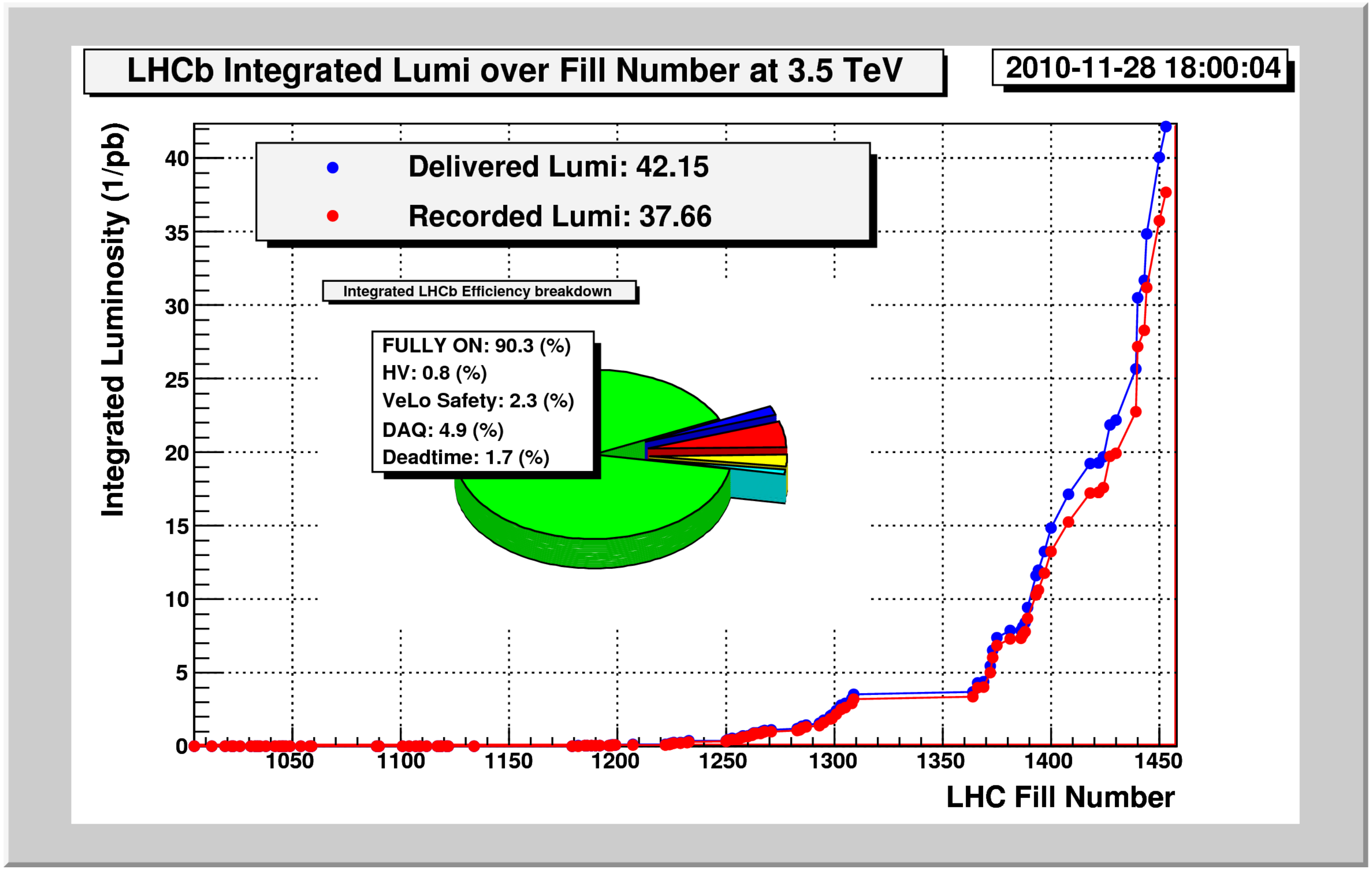
vertex detector



tracking system
momentum resolution $\delta p/p \sim 0.5\%$

muon chambers

Integrated Luminosity

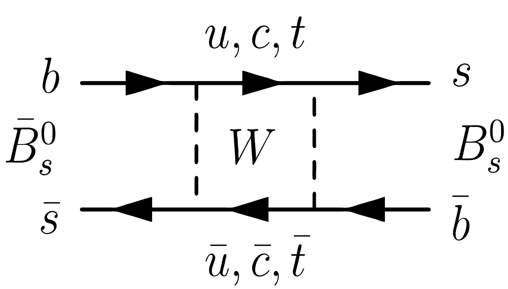


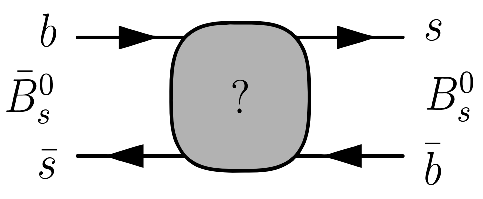
$B_s - \bar{B}_s$ mixing

Time development described by phenomenological Schroedinger eq.

$$i\frac{d}{dt}\begin{pmatrix}B_s\\ \bar{B}_s\end{pmatrix} = \left(\mathrm{M} - \frac{i}{2}\Gamma\right)\begin{pmatrix}B_s\\ \bar{B}_s\end{pmatrix}$$

$$\underset{\text{Diag.}}{\Longrightarrow} \quad \begin{aligned} i\frac{d}{dt}B_L &= (M_L - \tfrac{i}{2}\Gamma_L)B_L \\ i\frac{d}{dt}B_H &= (M_H - \tfrac{i}{2}\Gamma_H)B_H \end{aligned}$$





Mixing parameters: $\Delta\Gamma = \Gamma_L - \Gamma_H$

$$\Delta m = m_L - m_H$$

$$\phi_s = 2\arg V_{ts} V_{tb}^*$$

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

complex

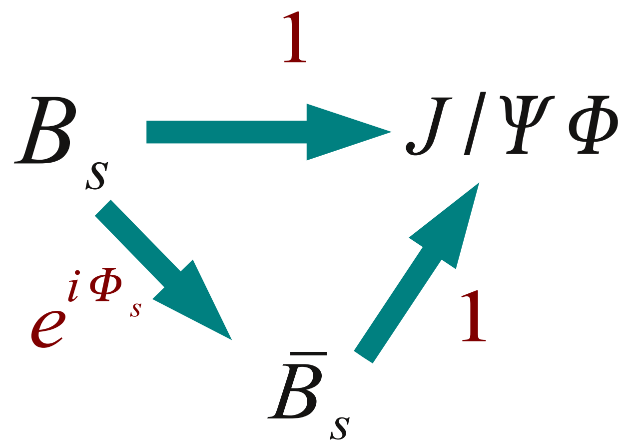
New Physics (e.g SUSY particles in mixing):

→ different mixing amplitude and phase Φ_s

$$\phi_s \rightarrow \phi_{SM} + \phi_{NP}$$

CP violation in $B_s \rightarrow J/\Psi\ \Phi$

CP violation only in **interference** of mixing and decay:



for CP eigenstates: $CP(f) = \eta_{CP}(f)$

CP asymmetry:
$$A_{CP}(t) = \frac{\Gamma(\bar{B}_s(t) \rightarrow (J/\psi\,\phi)_{CP}) - \Gamma(B_s(t) \rightarrow (J/\psi\,\phi)_{CP})}{\Gamma(\bar{B}_s(t) \rightarrow (J/\psi\,\phi)_{CP}) + \Gamma(B_s(t) \rightarrow (J/\psi\,\phi)_{CP})} = -\eta_{CP} \sin\Phi_s \sin(\Delta m \cdot t)$$

But: J/Ψ Φ is not a CP eigenstate!!

Separation of CP eigenstates

B_s (spin 0) decays into two vector particles J/Ψ and Φ with spin 1

→ relative angular momentum L = 0,1,2

$$CP(J/\Psi\,\Phi) = \eta_{CP}(J/\Psi)\cdot\eta_{CP}(\Phi)\cdot(-1)^l$$

η_{CP}(J/Ψ Φ)	L	Amplitude
+1	0	A_0, A_{II}
-1	1	$A_\perp$
+1	2	A_0, A_{II}

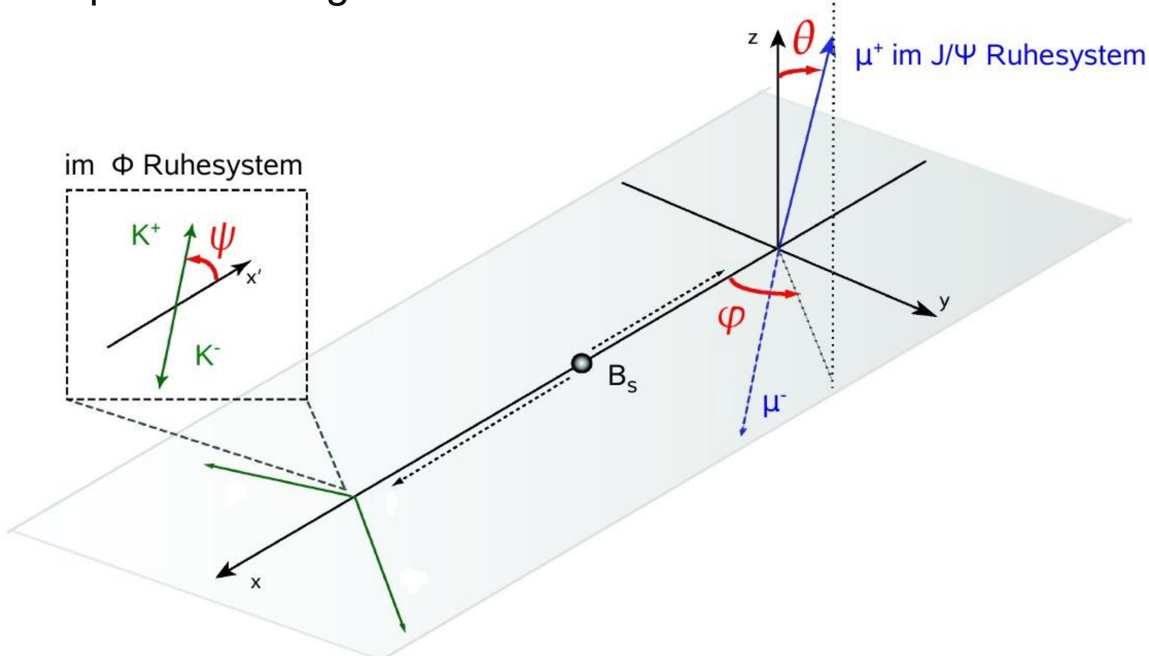
decay described in the basis of three "transversity angles"

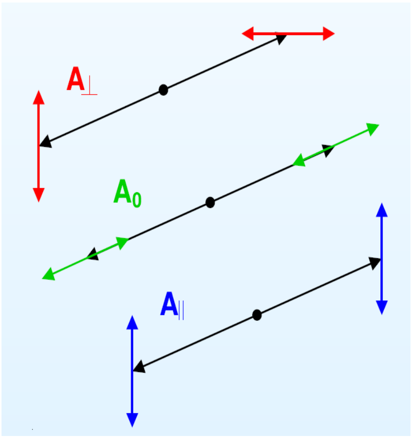
→ combined fit of lifetime and angular distributions to separate CP eigenstates

A_0 longitudinal polarisation

A_{II} parallel polarisation

$A_\perp$ perpendicular polarisation

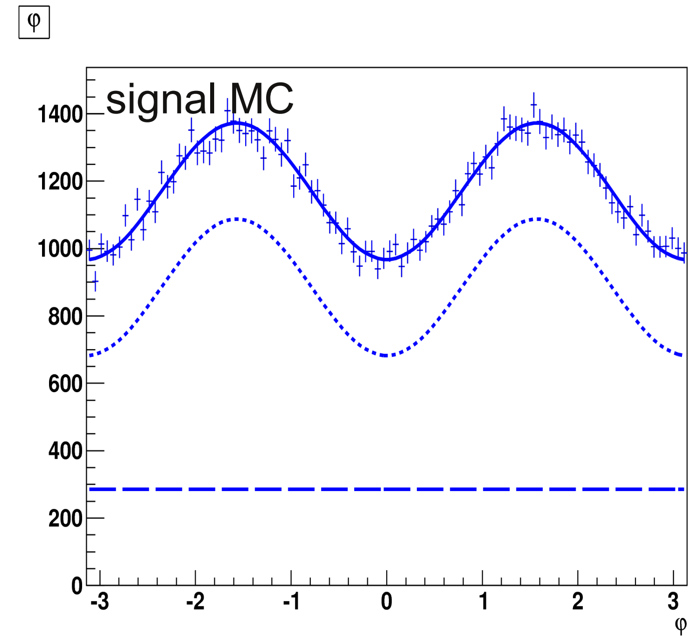


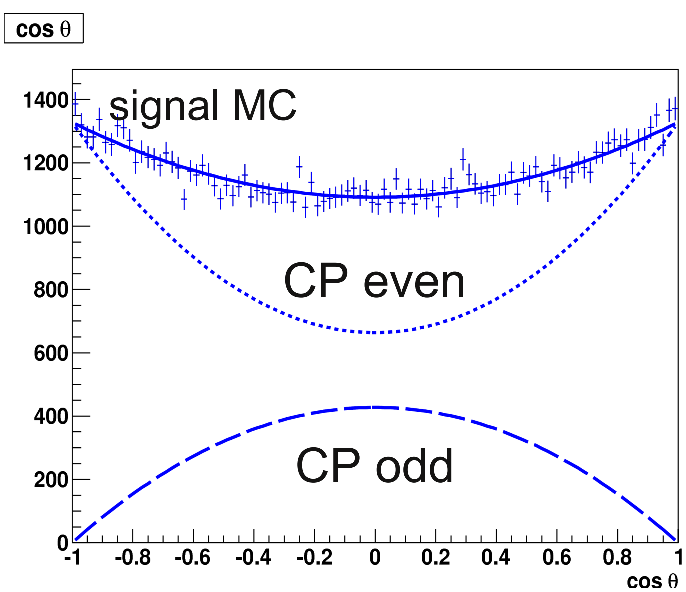


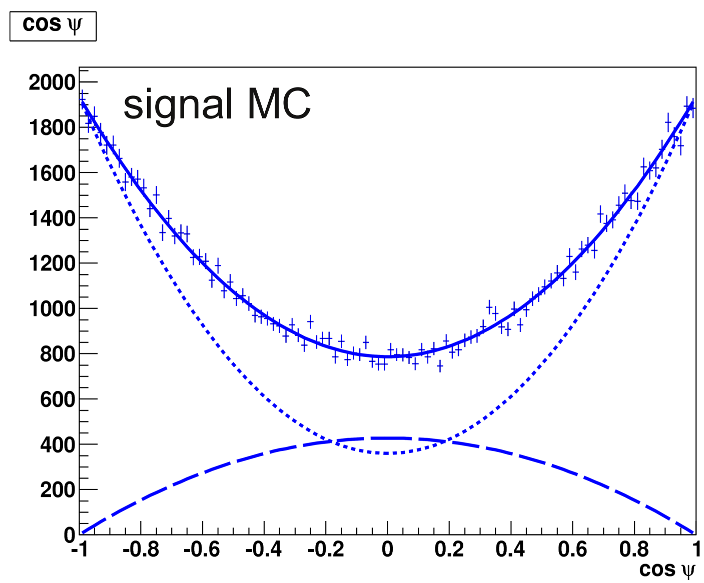
Separation of CP eigenstates

Separation of CP even and CP odd states:

Different shapes in angular distributions and proper time

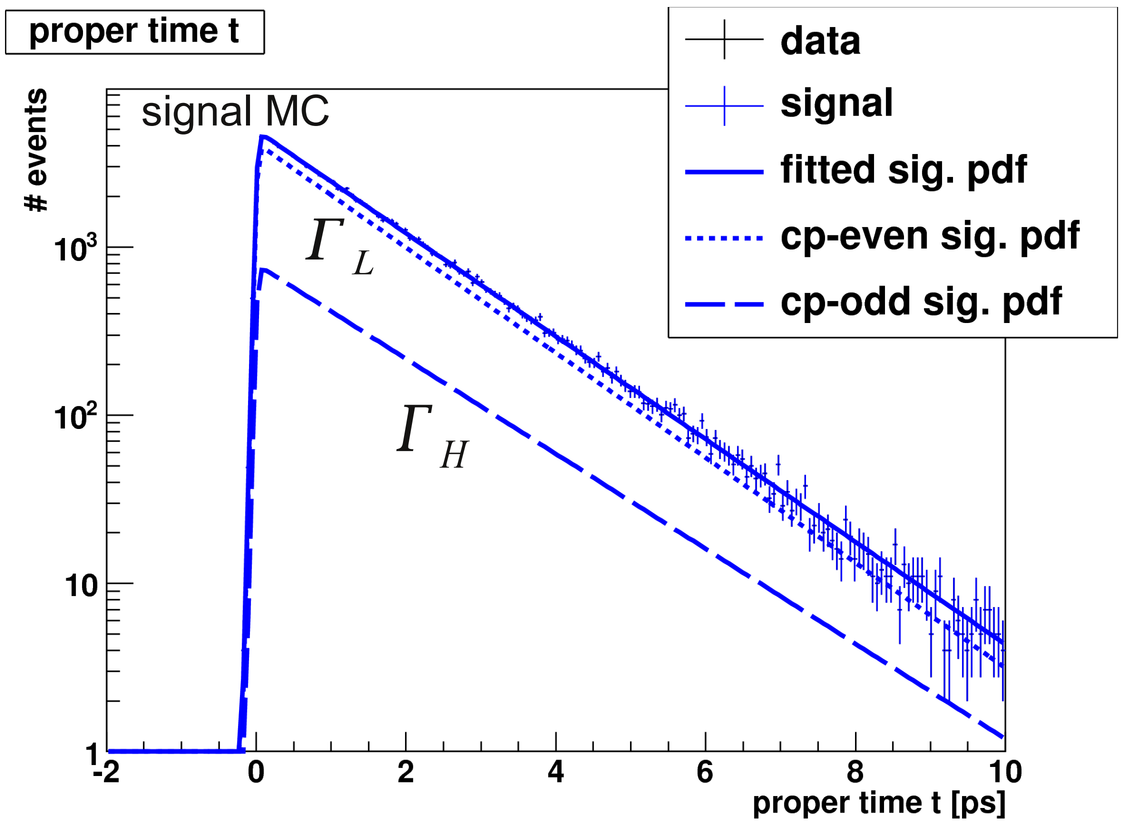






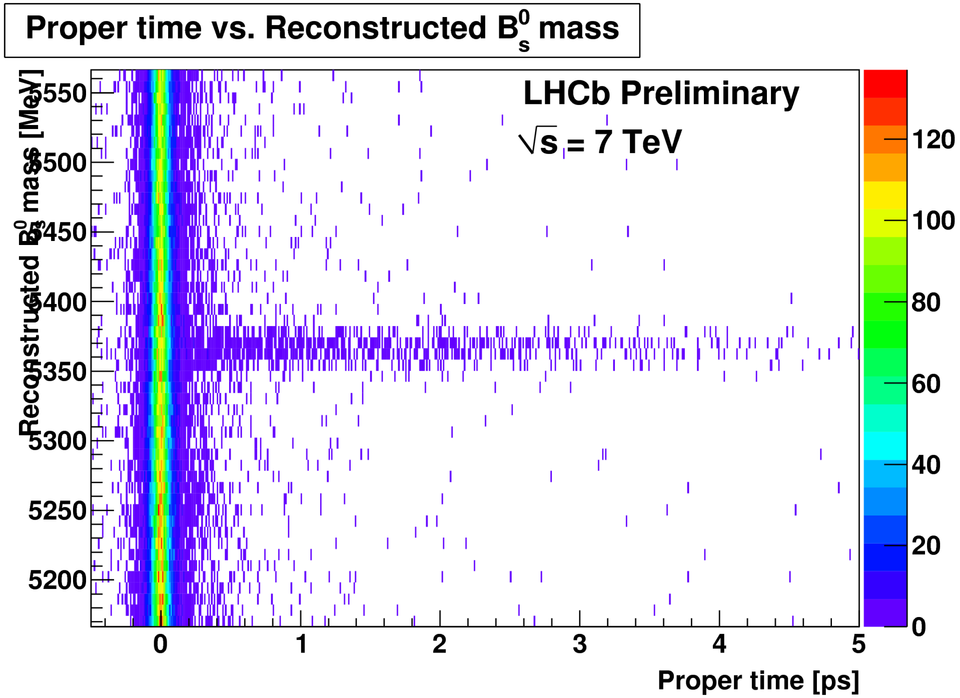
Separation of CP eigenstates

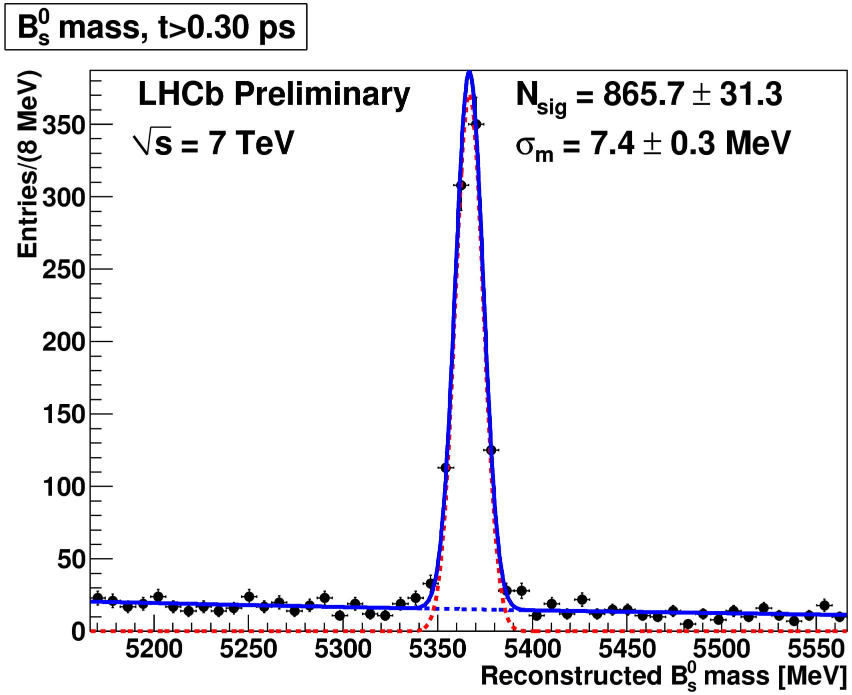
Separation of CP eigenstates allows measurement of Γ_L, Γ_H, $\Delta\Gamma$



Reconstruction of $B_s \rightarrow J/\Psi\ \Phi$

- data corresponds to $37pb^{-1}$ integrated luminosity
- clean signal for t > 0.3 ps
  (reduces prompt background)





Ingredients for the analysis

Time resolution: fast B_s oszillation needs to be resolved: $\Delta m_s = 17.8\ ps^{-1}$

$$A_{CP} = -\eta_{CP} \sin\Phi_s \sin(\Delta m \cdot t)$$

σ_t calibrated from prompt peak

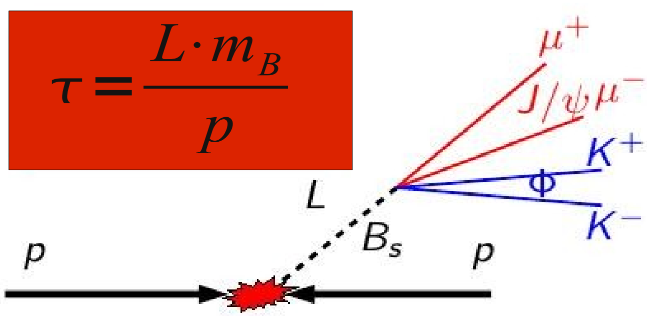
current resolution $\sigma_t \sim$ 60 fs

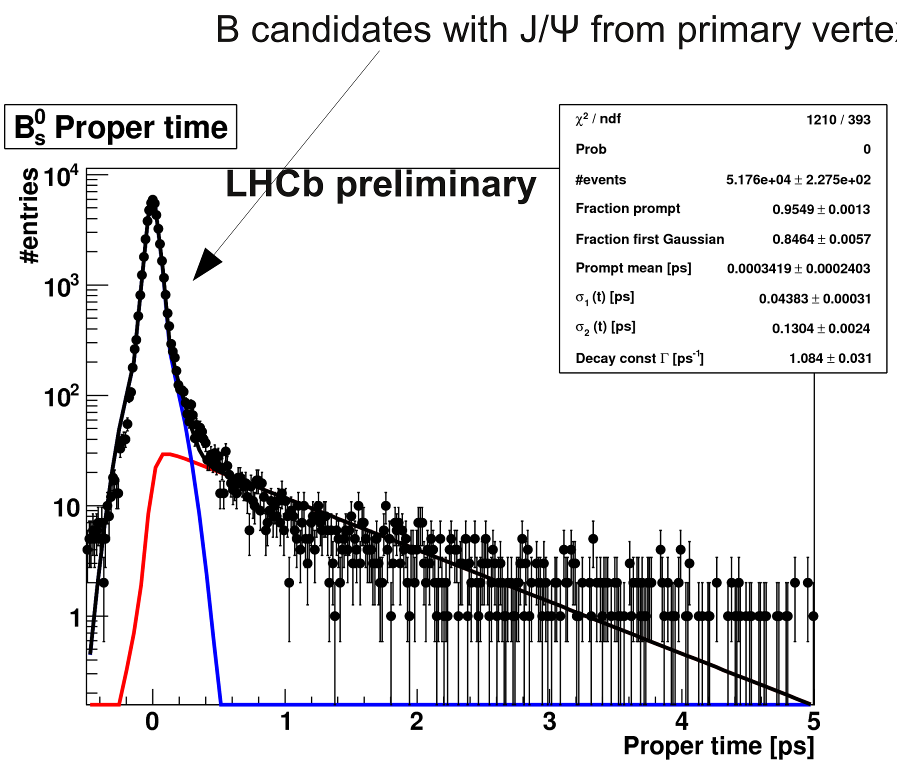
$$L = v \cdot t = \beta\gamma\tau$$

$$\beta = \frac{p}{E}$$

$$\gamma = \frac{E}{m_B}$$

$$\tau = \frac{L \cdot m_B}{p}$$





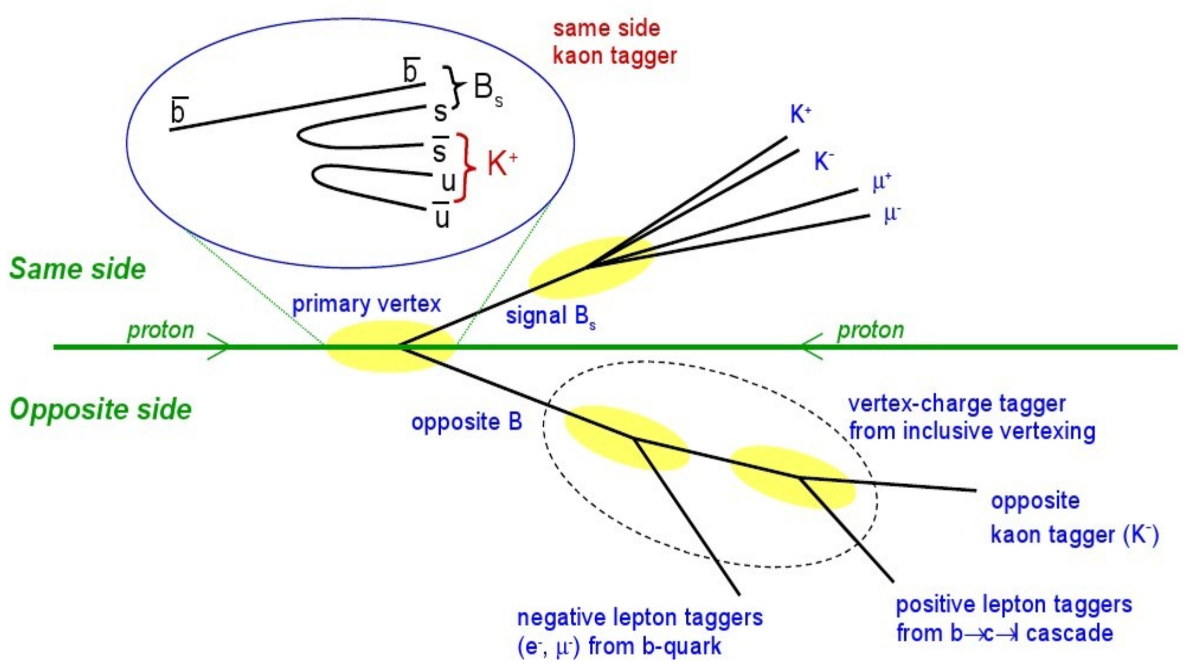
Ingredients for the analysis

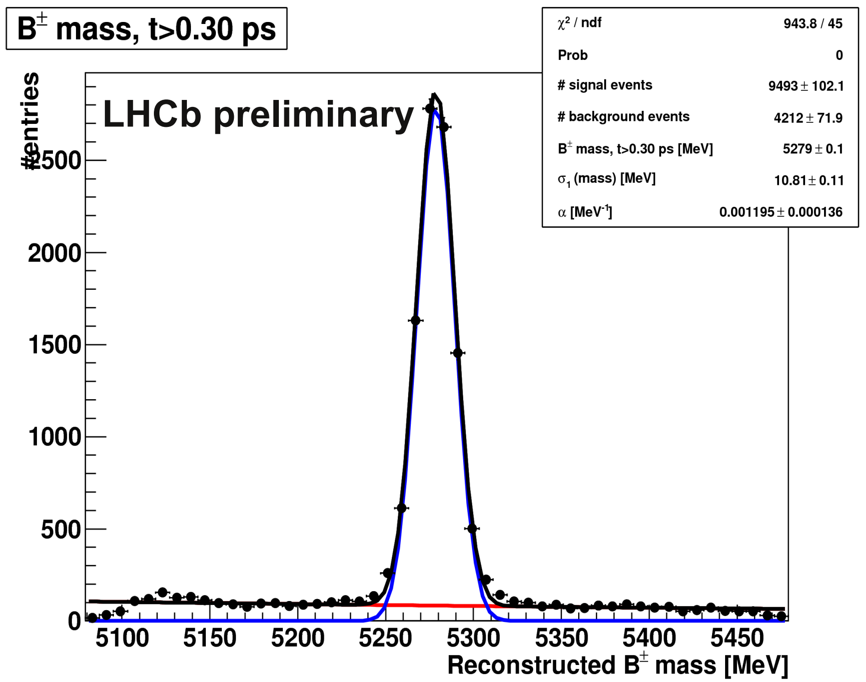
mistag probability
(50% → no information)

Tagging: determine flavour of B-meson at production

tagging has large impact on A_{CP} $A_{CP} = -\eta_{CP}(1-2\omega)\sin\Phi_s \sin(\Delta m \cdot t)$

efficiency and mistag rate from controll channel (e.g. $B^+ \rightarrow J/\Psi\, K^+$)





Ingredients for the analysis

detector acceptances: can influence the lifetime and angular distributions
→ check with control channel $B_d \to J/\Psi\ K^*$

$B_d \to J/\Psi\ K^*$

($J/\Psi \to \mu\mu$)
($K^* \to K\ \pi$)

- same angular analysis as in $B_s \to J/\Psi\ \Phi$ ($P \to VV$)

  → decay described by three polarisation amplitudes: A_0, $A_{\parallel}$, $A_{\perp}$

- good statistics (650 000 events per 2fb-1)

- already measured precisley by BaBar, Belle, CDF, D0

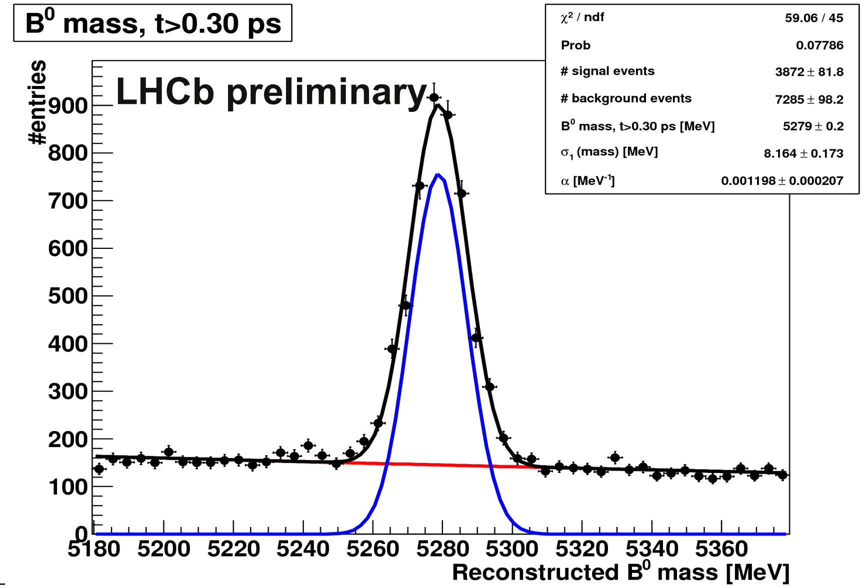
  → very good cross check for validation of detector acceptances

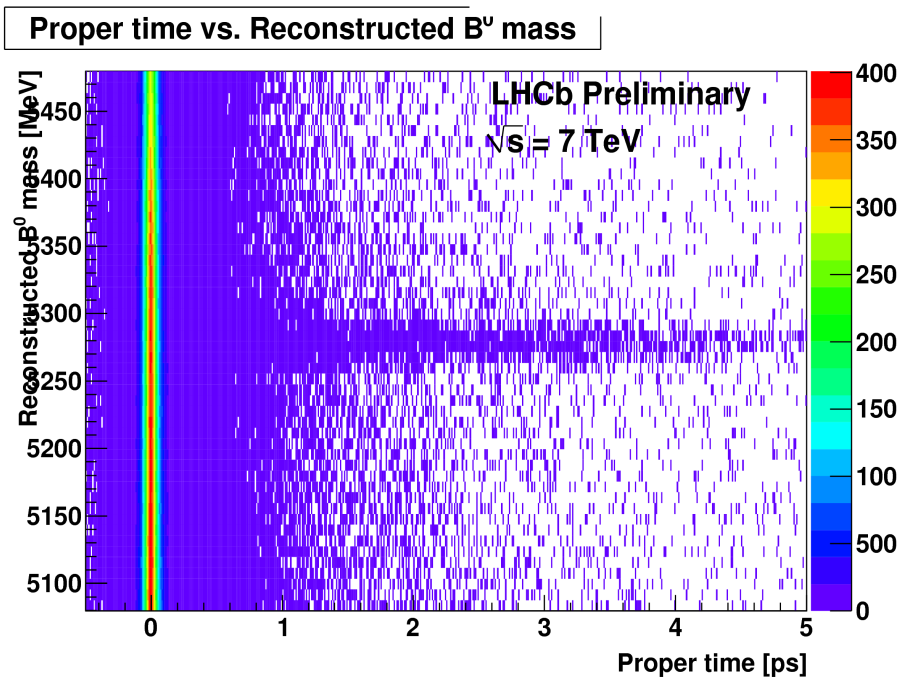
Parameter	Babar (2007)	Belle (2002)	CDF (2007)	DØ (2009)
$\|A_{\parallel}\|^2$	$0{,}211 \pm 0{,}010 \pm 0{,}006$	-	$0{,}211 \pm 0{,}012 \pm 0{,}006$	$0{,}230 \pm 0{,}013 \pm 0{,}025$
$\|A_0\|^2$	$0{,}556 \pm 0{,}009 \pm 0{,}010$	$0{,}617 \pm 0{,}020 \pm 0{,}027$	$0{,}569 \pm 0{,}009 \pm 0{,}009$	$0{,}587 \pm 0{,}011 \pm 0{,}013$
$\|A_{\perp}\|^2$	$0{,}233 \pm 0{,}010 \pm 0{,}005$	$0{,}192 \pm 0{,}023 \pm 0{,}026$	-	-
$\delta_{\parallel}$ [rad]	$-2{,}93 \pm 0{,}08 \pm 0{,}04$	$2{,}83 \pm 0{,}19 \pm 0{,}08$	$-2{,}96 \pm 0{,}08 \pm 0{,}03$	-
$\delta_{\perp}$ [rad]	$2{,}91 \pm 0{,}05 \pm 0{,}03$	$-0{,}09 \pm 0{,}13 \pm 0{,}06$	$2{,}97 \pm 0{,}06 \pm 0{,}01$	-

Selection $B_d \rightarrow J/\Psi\ K^*$

Selection based on:

- transverse momentum cuts
- track quality cuts
- cuts on quality of vertex reconstruction
- PID cuts
- cut on B_d lifetime





Likelihood Fit

For determination of physical parameters:
→ Maximum likelihood method

parameters (physic + detector)

observables

$$\mathcal{L}(\vec{\lambda}) = \prod_{i}^{all\ \ events} p_i(\vec{\lambda}, X)$$

probability density function (pdf)

Maximizing $\mathcal{L}(\vec{\lambda})$ by variation of $\vec{\lambda}$ maximizes the probability to measure X

$$p(\vec{\lambda}, X) = f_{sig} \cdot S(\vec{\lambda}, X) + (1 - f_{sig}) \cdot B(\vec{\lambda}, X)$$

signal pdf model   background pdf model

Including acceptance effects: $S(\vec{\lambda}, X) \rightarrow \varepsilon(X) \cdot S(\vec{\lambda}, X)$

Analysis strategy for Bd->Jpsi K*

Perform unbinned maximum likelihood fit to disentangle angular momentum states:

time dependent part — angular dependent part

Decay rate: $$\frac{d^4\Gamma}{dt\ d\cos\psi\ d\phi\ d\cos\theta} = e^{-\Gamma_d \cdot t} \cdot \sum A_i \cdot f_i(\cos\psi, \cos\theta, \phi)$$

Observables: cosθ, cosψ, φ, t

Physics parameter: $|A_{\|}|^2$ $|A_{\perp}|^2$ $\delta_{\|}$ $\delta_{\perp}$ Γ_d

$$A_{\|} = |A_{\|}| \cdot e^{i\delta_{\|}}$$
$$A_{\perp} = |A_{\perp}| \cdot e^{i\delta_{\perp}}$$
$$A_0 = |A_0| \cdot e^{i\delta_0}$$
$$|A_{\|}|^2 + |A_{\perp}|^2 + |A_0|^2 = 1$$

detector parameters:

- time resolution, ← convoluting pdfs with gaussian
- mass resolution,
- background description, ← fractions, shapes (prompt – longlived)
- ...

no CP violation, untagged fit

Analysis strategy for Bd->Jpsi K*

Perform unbinned maximum likelihood fit to disentangle angular momentum states:

Decay rate:

$$\frac{d^4\Gamma}{dt\,d\cos\theta\,d\varphi\,d\cos\psi} = e^{-\Gamma_d t}\cdot\left[\,f_1|A_0|^2 + f_2|A_\parallel|^2 + f_3|A_\perp|^2 - f_4 A_\parallel A_\perp \sin(\delta_\perp - \delta_\parallel)\right.$$
$$\left. + f_5 A_0 A_\parallel \cos\delta_\parallel + f_6 A_\perp A_0 \sin\delta_\perp\,\right].$$

$f_k(\theta,\psi,\varphi)$
$\frac{9}{32\pi} 2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)$
$\frac{9}{32\pi}\sin^2\psi(1-\sin^2\theta\sin^2\varphi)$
$\frac{9}{32\pi}\sin^2\psi\sin^2\theta$
$-\frac{9}{32\pi}\sin^2\psi\sin 2\theta\sin\varphi$
$\frac{9}{32\pi}\frac{1}{\sqrt{2}}\sin 2\psi\sin^2\theta\sin 2\varphi$
$\frac{9}{32\pi}\frac{1}{\sqrt{2}}\sin 2\psi\sin 2\theta\cos\varphi$

Observables: cosθ, cosψ, φ, t

Physics parameter: $|A_\parallel|^2$ $|A_\perp|^2$ $\delta_\parallel$ $\delta_\perp$ Γ_d

detector parameters:
- time resolution, ← convoluting pdfs with gaussian
- mass resolution,
- background description, ← fractions, shapes (prompt – longlived)
- ...

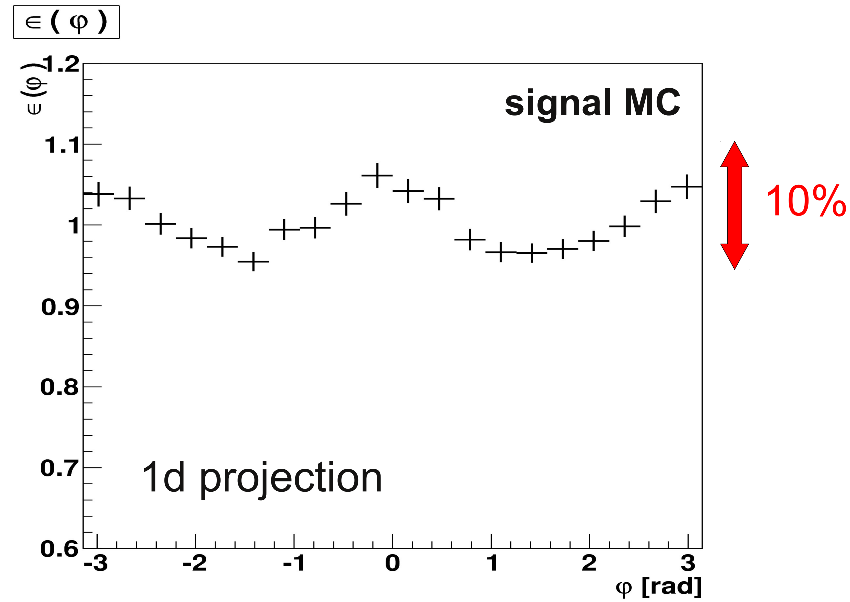
no CP violation, untagged fit

Angular acceptances in $B_d \to J/\Psi K^*$

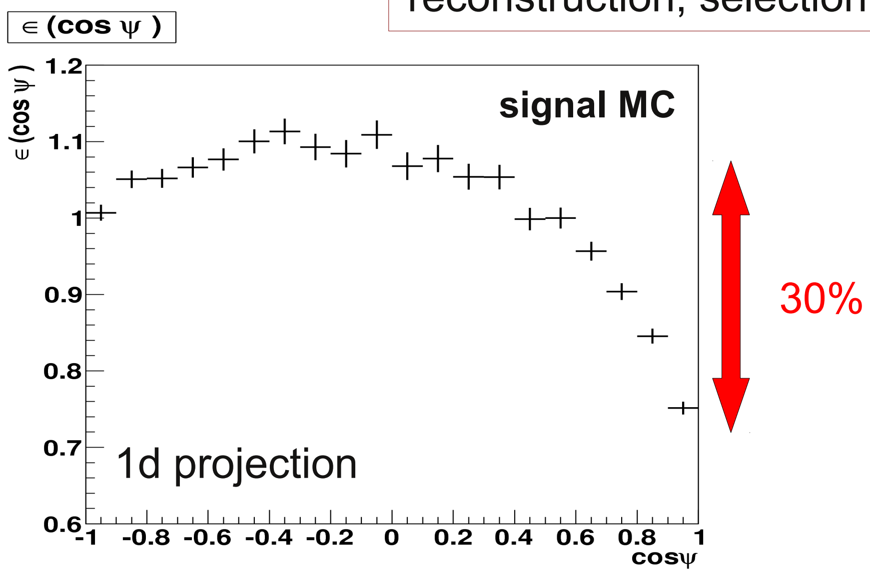
- Angular acceptances deform the signal angular distributions
- Have to calculate angular acceptances from MC

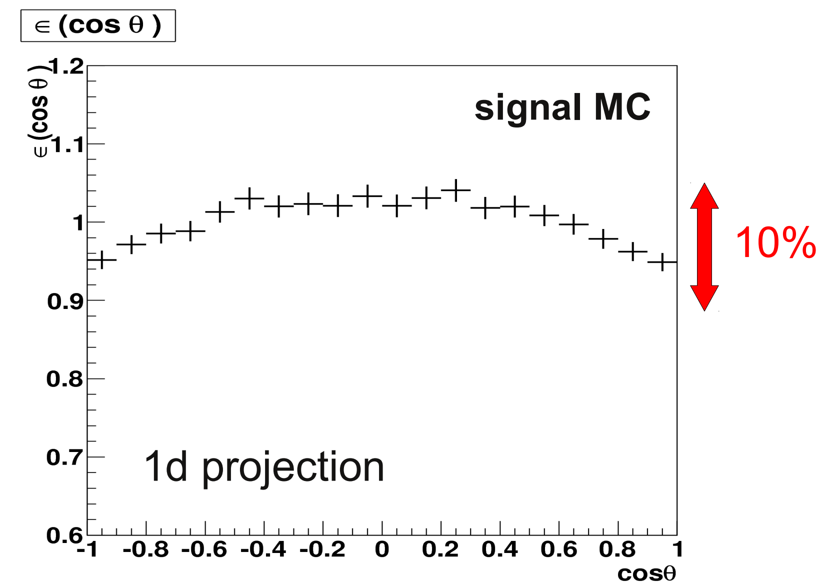
Acceptance calculation: 3 dimensional

$$\varepsilon(\cos\theta, \cos\psi, \phi) = \frac{MC \quad particles(\cos\theta, \cos\psi, \phi)}{theory \quad distribution(\cos\theta, \cos\psi, \phi)}$$



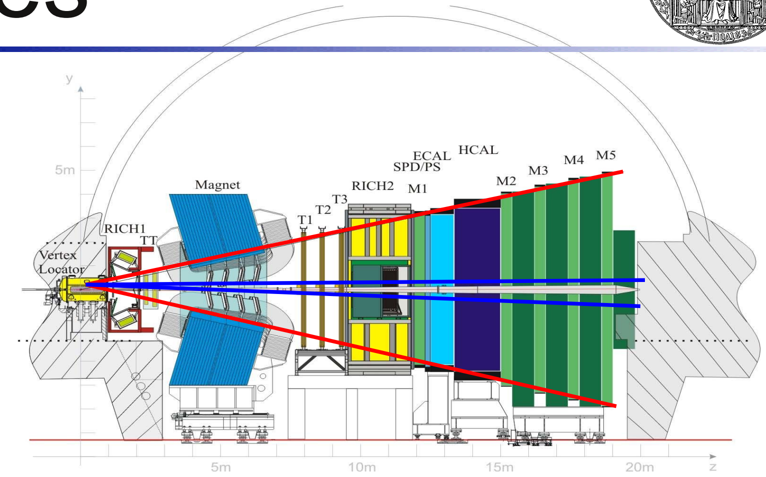
acceptance includes effects of:
reconstruction, selection, trigger,...





$B_d \rightarrow J/\Psi\ K^*$ acceptances

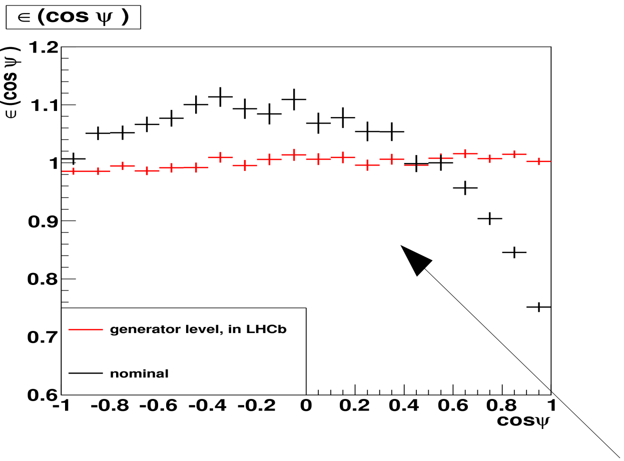
How are acceptances determined?

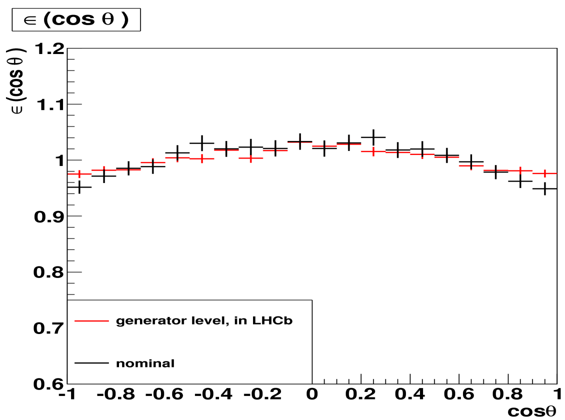


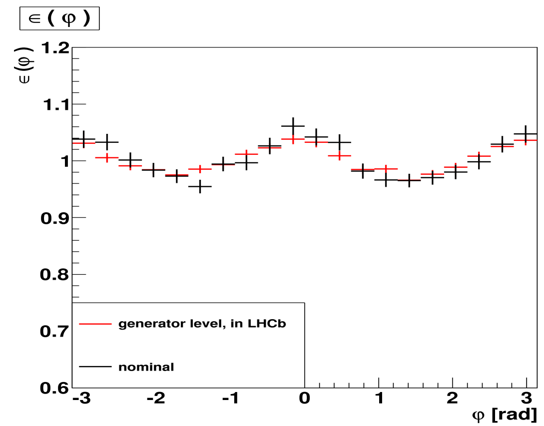
detector angular cut
+
reconstruction
+
selection
+
trigger

detector region: 10 mrad < Θ < 400 mrad

Black: include all effects of reconstruction, selection, …
Red: only detector angular cut







remaining reconstruction effects

$B_d \rightarrow J/\Psi K^*$ acceptances

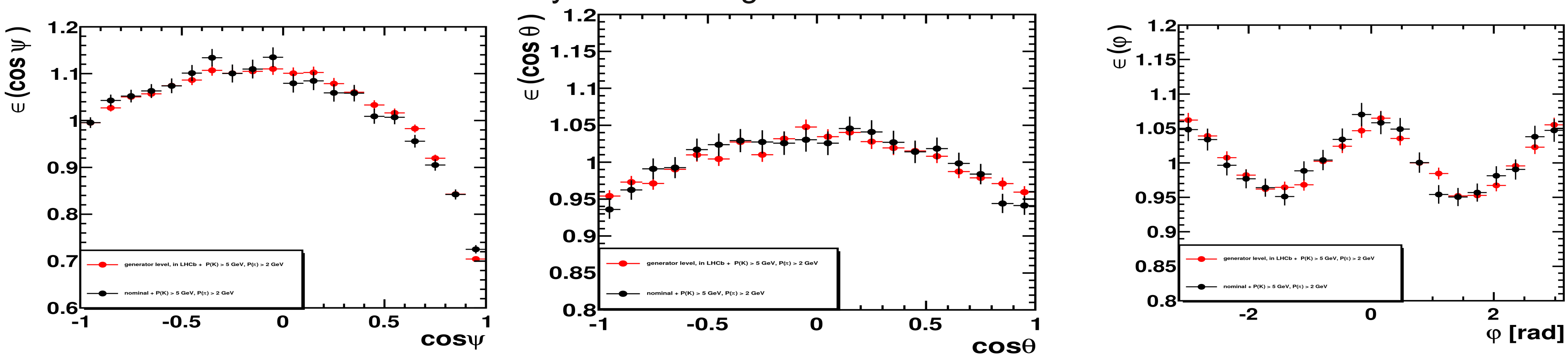
How are acceptances determined?

detector angular cut
+
reconstruction
+
selection
+
trigger

implicit momentum cut in reconstruction!

→ apply cut on P(K) > 5Gev
P(pi) > 2GeV

Black: include all effects of reconstruction, selection, …
Red: only detector angular cut + momentum cuts



$B_d \to J/\Psi K^*$ acceptances

How are acceptances determined?

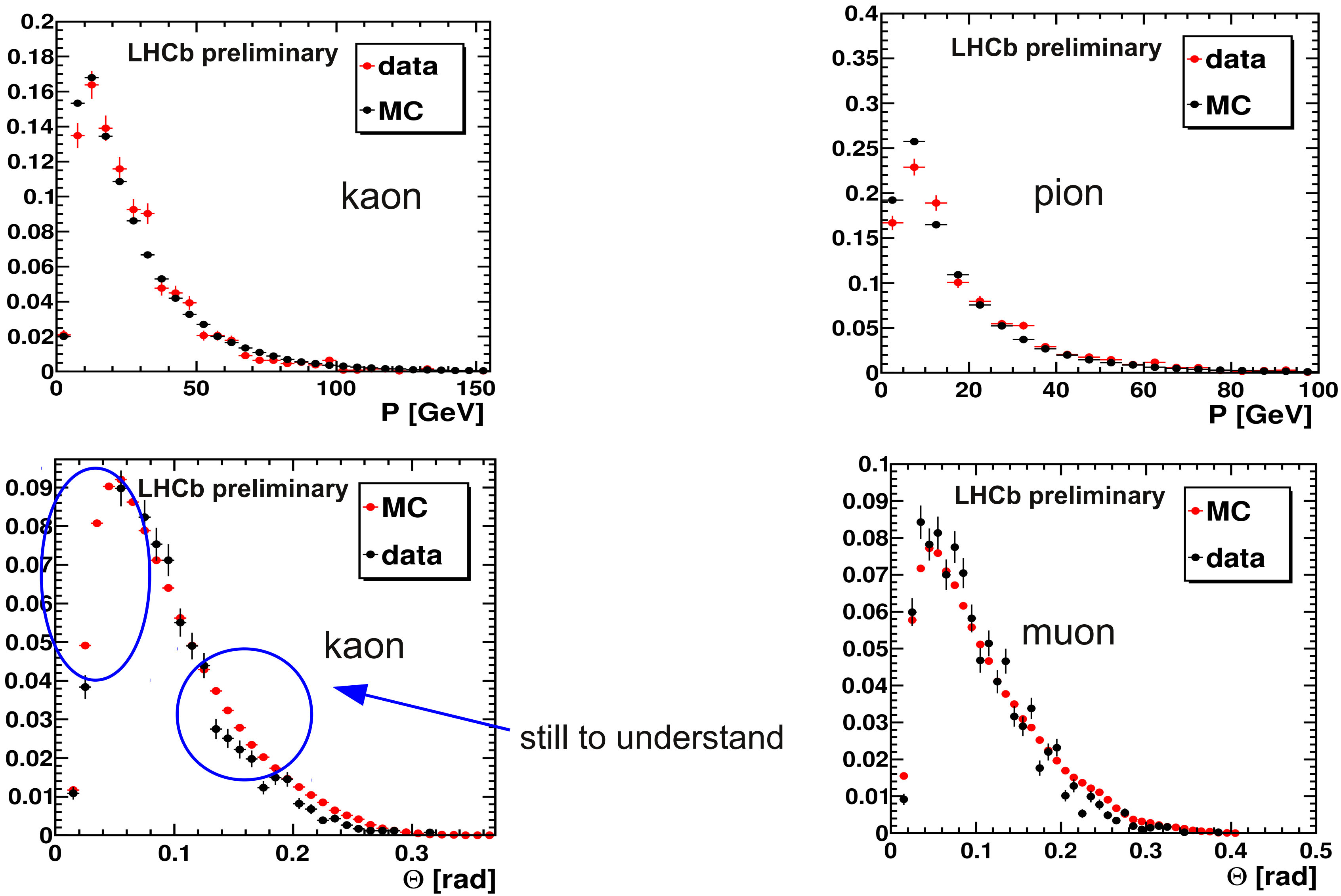
detector angular cut
+
reconstruction
+
selection
+
trigger

→ only very small effects

→ acceptance determined by detector angular cut and momentum cut in reconstruction

Kinematic distributions data - MC

How large is the difference between data and MC in theese variables?



Systematic studies acceptances

How can we estimate the systematic uncertainties due to acceptance calculation?

→ toy experiments simulating wrong acceptances:

Acceptance modification	deviation in σ_{stat} from nominal value			
	$\|A_{\|\|}\|^2$	$\|A_{\perp}\|^2$	$\delta_{\|\|}$	$\delta_{\perp}$
changing detector cut:				
12.5 mrad < Θ < 375 mrad	0.07	0.20	0.13	0.14
15 mrad < Θ < 350 mrad	0.06	0.25	0.01	0.04
changing momentum cut:				
P (K) > 4.9 GeV P (π) > 1.9 GeV	0.10	0.10	0.13	0.10
P (K) > 5.1 GeV P (π) > 2.1 GeV	0.10	0.24	0.15	0.13

no large deviations compared to statistical error

→ have to assign only small systematic uncertainties due to acceptance description

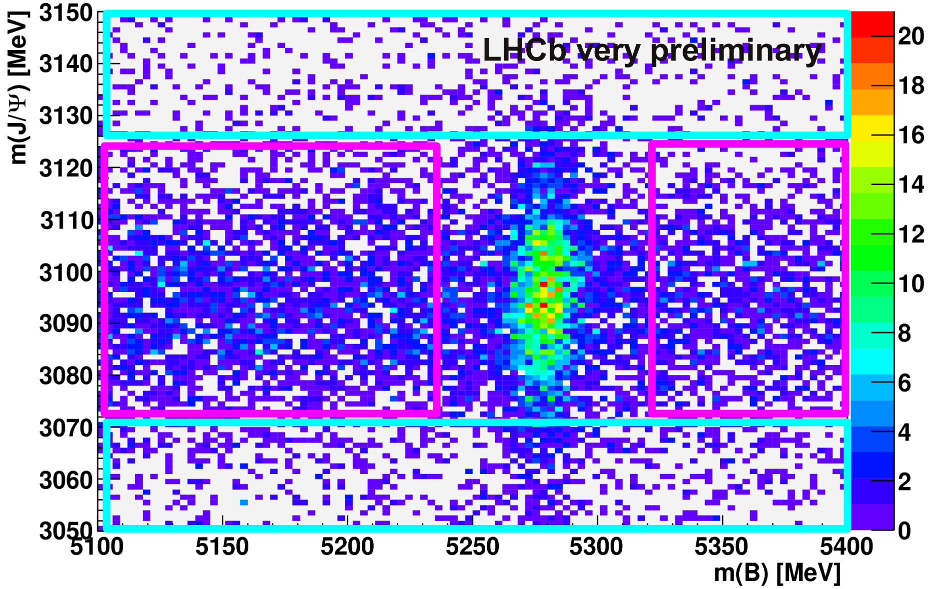
$B_d \rightarrow J/\Psi K^*$ background

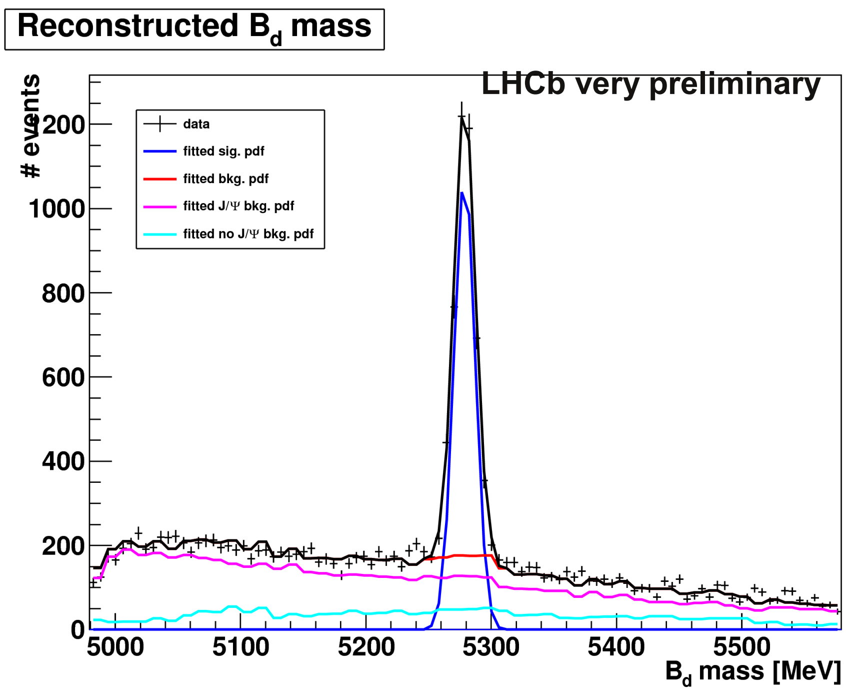
Different background sources:

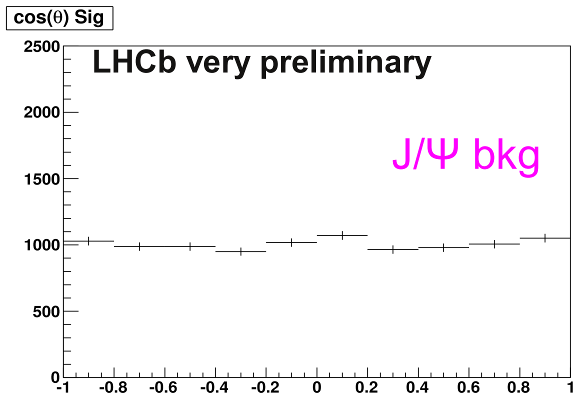
B candidates from real J/Ψ

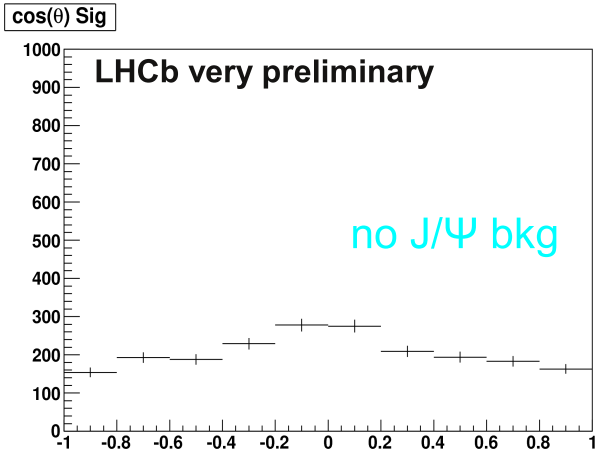
background from other combinatorics

→ different angular distributions

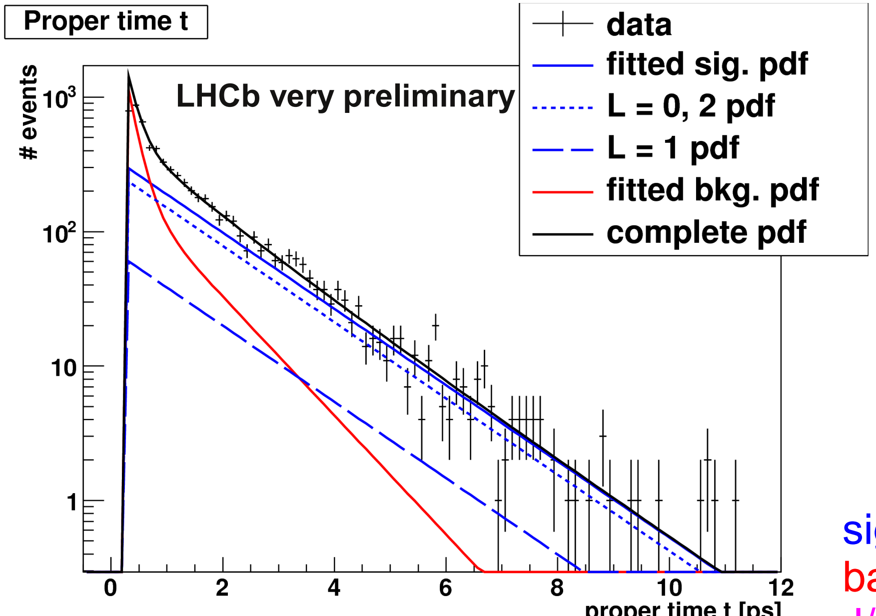


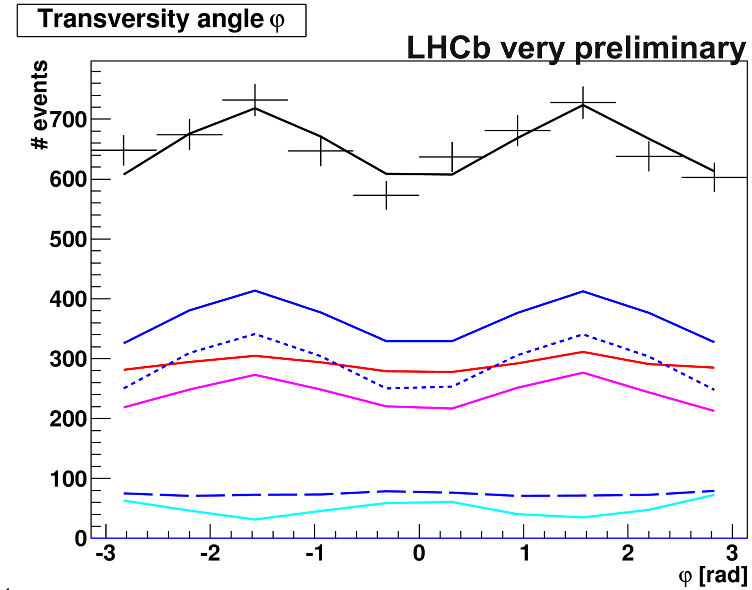




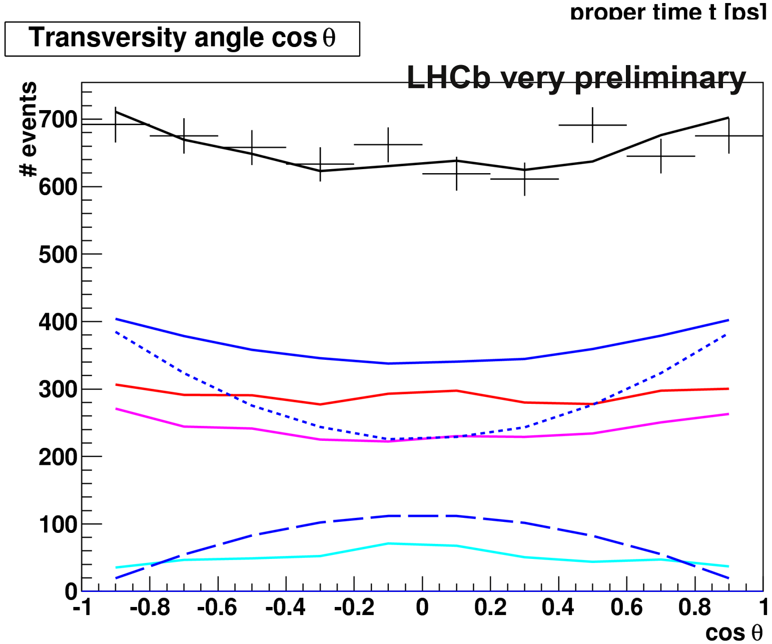


$B_d \to J/\Psi\ K^*$ fit projections

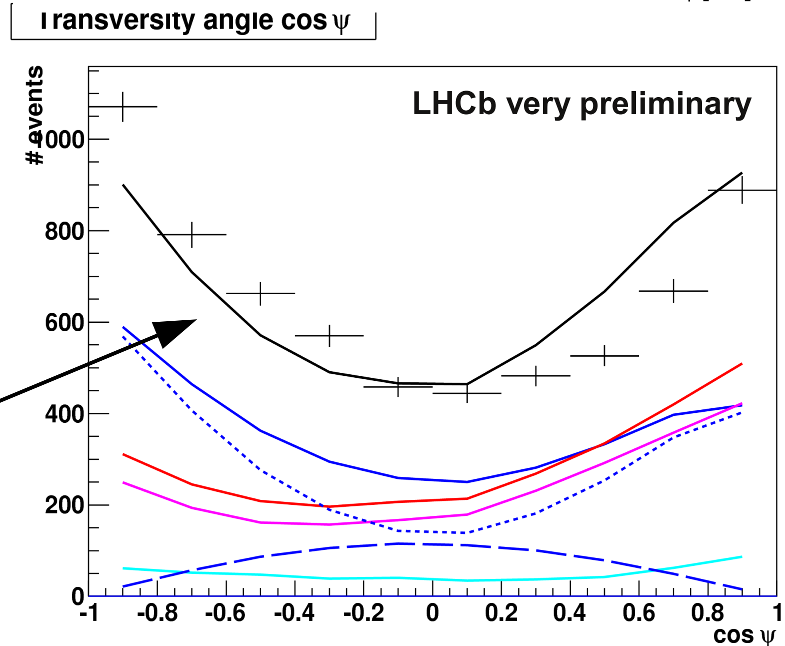




signal pdf
background pdf
J/Ψ bkg pdf
no J/Ψ bkg pdf



still to understand



$B_d \rightarrow J/\Psi K^*$ sensitivity

Expected sensitivity on the polarisation amplitudes:

for 37 pb^{-1}

parameter	sensitivity
$\lvert A_{\parallel}\rvert^2$	0.021
$\lvert A_{\perp}\rvert^2$	0.020
$\delta_{\parallel}$	0.12
$\delta_{\perp}$	0.099

for 2 fb^{-1}

parameter	sensitivity
$\lvert A_{\parallel}\rvert^2$	0.001
$\lvert A_{\perp}\rvert^2$	0.001
$\delta_{\parallel}$	0.007
$\delta_{\perp}$	0.006

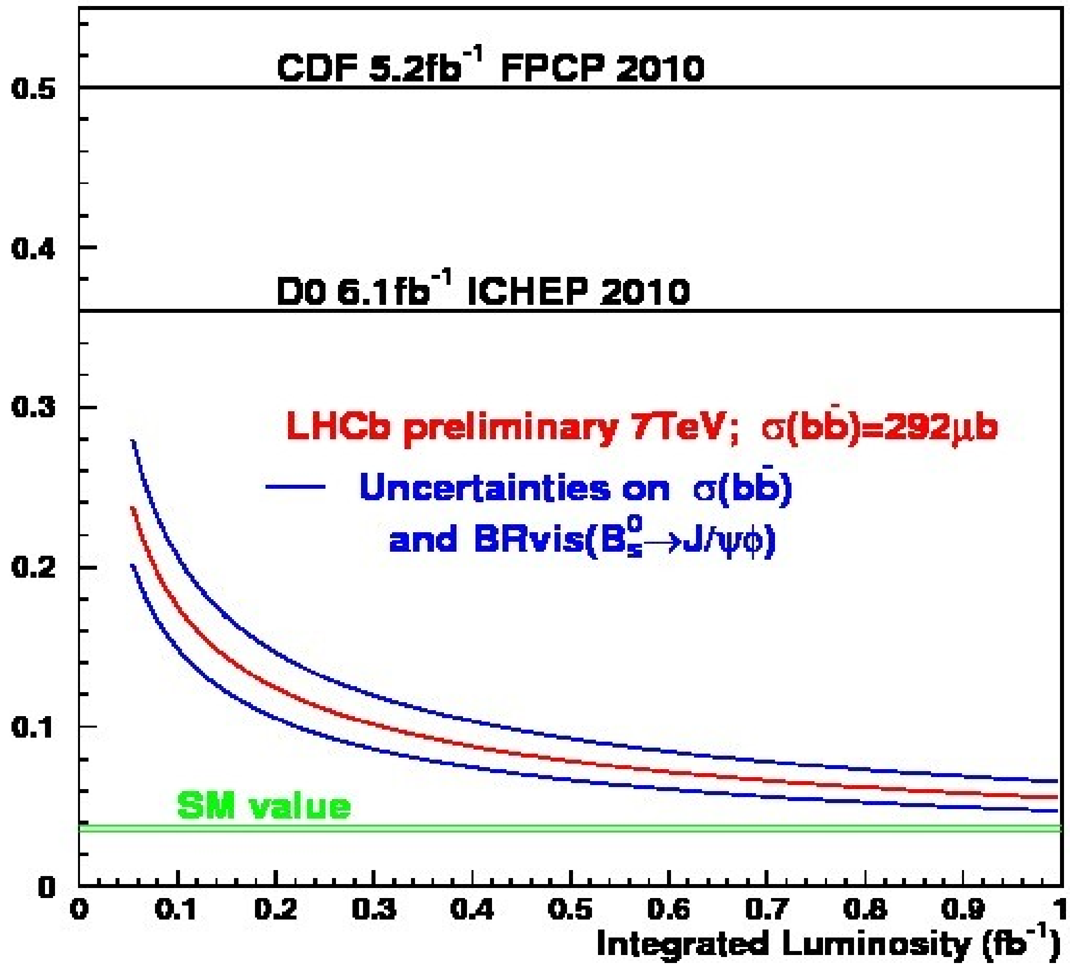
parameter	sensitivity			
	Babar (2007) stat. / syst.	Belle (2002) stat. / syst.	CDF (2007) stat. / syst.	DØ (2009) stat. / syst.
$\lvert A_{\parallel}\rvert^2$	0.010 / 0.006	-	0.012 / 0.006	0.013 / 0.025
$\lvert A_{\perp}\rvert^2$	0.009 / 0.010	0.020 / 0.027	0.009 / 0.009	0.011 / 0.013
$\delta_{\parallel}$	0.08 / 0.04	0.19 / 0.08	0.08 / 0.03	-
$\delta_{\perp}$	0.05 / 0.03	0.13 / 0.06	0.06 / 0.01	-

→ with current statistics not yet competetive with other experiments

→ with 2fb-1 larger statistical sensitivity

$B_s \rightarrow J/\Psi\ \Phi$ prospects for 2011

Important ingredients: proper time resolution, tagging efficiency, acceptances



Monte Carlo assumptions:

- proper time resolution:

  $\sigma_t = 0.038$ ps
  (in data still ~ 1.3x worse)

- tagging efficiency:

  $\varepsilon D^2 = 6.2\%$
  (not yet calibrated with data)

Conclusion

- B_s meson system offers probability to search for New Physics

  → CP violation is a very sensitive observable

- The prototype channel to search for New Physics is $B_s \to J/\Psi\ \Phi$
  Very involved analysis, requires many steps:

  proper time calibration

  tagging calibration

  detector acceptances

  ↓

  my current work: measuring the polarisation amplitudes in $B_d \to J/\Psi\ K^*$

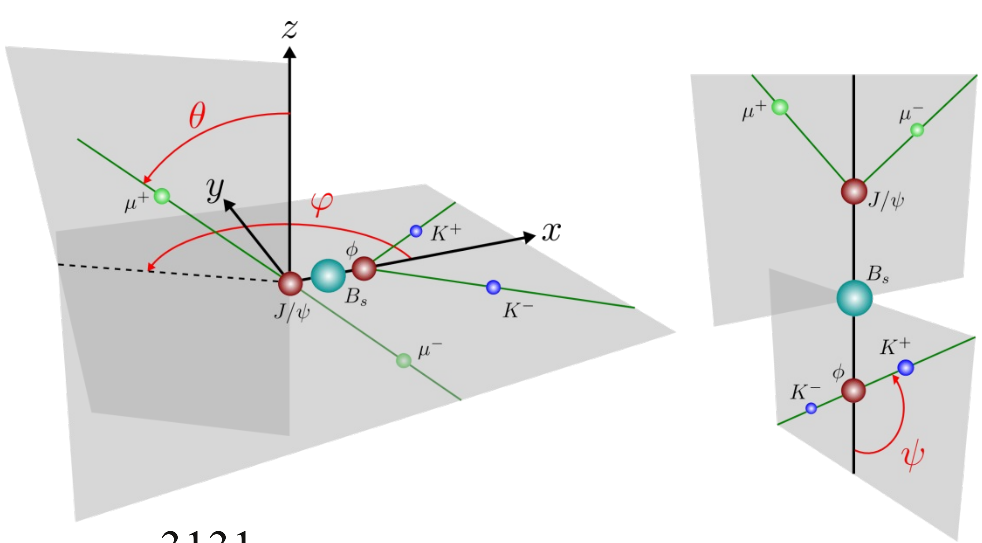
  test the angular acceptances

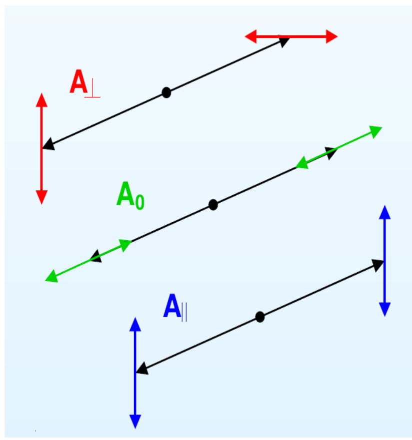
first results shown today → hope to have publishable results by March 2011

BACKUP

Transversity Basis

- Bs is a pseudo scalar (spin=0), ϕ and J/ψ are vectors mesons (JPC = 1—)
- Total angular momentum conservation □
  in the Bs rest frame, ϕ and J/ψ have relative orbital momentum ℓ =0,1,2
- Since CP|J/□□>= (-1)ℓ|J/□□>,
  final state is mixture of CP even (ℓ=0,2) and CP odd (ℓ=1)
- Decompose decay amplitudes in term of linear polarization, when J/ψ and ϕ are:
  - A0: longitudinally polarized (CP-even)
  - A⊥: transversely polarized and ⊥ to each other (CP-odd)
  - A||: transversely polarized and ‖ to each other (CP-even)
- □ 3 angles θ, ϕ, ψ describe directions of final decay products J/ψ→$\mu\mu$, □→K+K





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